# Analysis of the Capacity Potential of Current Day and Novel Configurations for New York's John F. Kennedy Airport

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**In 2015, a series of systems analysis studies were conducted on John F. Kennedy Airport in New York (NY) in a collaborative effort between NASA and the Port Authority of New York and New Jersey (PANYNJ). This work was performed to build a deeper understanding of NY airspace and operations to determine the improvements possible through operational changes with tools currently available, and where new technology is required for additional improvement. The analysis was conducted using tool-based mathematical analyses, video inspection and evaluation using recorded arrival/departure/surface traffic captured by the Aerobahn tool (used by Kennedy Airport for surface metering), and aural data archives available publically through the web to inform the video segments.**

**A discussion of impacts of trajectory and operational choices on capacity is presented, including runway configuration and usage (parallel, converging, crossing, shared, independent, staggered), arrival and departure route characteristics (fix sharing, merges, splits), and how compression of traffic is staged. The authorization in March of 2015 for New York to use reduced spacing under the Federal Aviation Administration (FAA) Wake Turbulence Recategorization (RECAT) also offers significant capacity benefit for New York airports when fully transitioned to the new spacing requirements, and the impact of these changes for New York is discussed.**

**Arrival and departure capacity results are presented for each of the current day Kennedy Airport configurations. While the tools allow many variations of user-selected conditions, the analysis for these studies used arrival-priority, no-winds, additional safety buffer of 5% to the required minimum spacing, and a mix of traffic typical for Kennedy. Two additional "novel" configurations were evaluated. These configurations are of interest to Port Authority and to their airline customers, and are believed to offer near-term capacity benefit with minimal operational and equipage changes. One of these is the addition of an Optimized Profile Descent (OPD) route to runways 22L and 22R, and the other is the simultaneous use of 4 runways, which is not currently done at Kennedy. The background and configuration for each of these is described, and the capacity results are presented along with a discussion of drawbacks and enablers for each.**

## I. Introduction

THIS This paper details work performed under the Regional TBO sub-project of the Shadow Mode Assessment using Realistic Technologies in the National Airspace System (SMART NAS) project. This work spanned January – August 2015, and was done in collaboration with Ames Research Center (ARC), Langley Research Center (LaRC), and the Port Authority of New York and New Jersey (PANYNJ). Trajectory Based Operations (TBO)

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leverage existing NASA and other NextGen technologies to enable precise scheduling and delivery of aircraft along coordinated trajectories [1]. Efficiency benefits for capacity, fuel usage, and delay are expected for the National Airspace System (NAS) through TBO operations. This work was performed to build a deeper understanding of New York (NY) airspace and operations to determine the improvements possible through operational changes with tools currently available, and where new technology is required for additional improvement. The analysis was performed using the Arrival Capacity Calculator (ACC) software tool and computational spreadsheets, in combination with subject matter expert input and video evidence, to capture the independent values needed for deriving the capacity of the airport under different configurations and conditions.

## Selection of JFK

The Port Authority is interested in quantifying the potential throughput for the NY airports as part of their ongoing delay reduction efforts. NY airports are currently capacity limited through Federal Aviation Administration (FAA) imposed maximum total operations per hour, or "slot caps". However, these caps were higher in the past, and Port Authority wants to know if these caps could be increased, especially in light of the recent adoption of Wake Recategorization (RECAT) for NY. RECAT is the redefinition of wake spacing requirements for the terminal airspace by the FAA. The FAA is rolling out RECAT gradually with a few airports at a time, and NY airports were allowed to use RECAT spacing as of March 2015. Aircraft types that benefit from the new spacing standards represent a significant portion of NY's typical traffic profile, and so this change is expected to benefit capacity for these airports. Tools and techniques in the NASA tool suite facilitate this type of airspace analysis. The tools can be configured to match real world current day routes or proposed novel routes to quantify potential capacity benefits objectively. The collaboration with Port Authority allowed significant insight into configuration of the scenarios to allow the tools to best match real-world operations.

New York has a complex airspace with three large commercial airports – John F. Kennedy International (JFK, or Kennedy), LaGuardia (LGA), and Newark Liberty International (EWR, or Newark). Teterboro (TEB) also shares the airspace, but is primarily used for business flights. The decision was made early in this task to focus on Kennedy Airport, which has more runway space but the same slot caps as Newark Airport. Both Newark and Kennedy may be capped at values below their true capacity in light of the recent adoption of RECAT, but JFK potentially has the largest mismatch because of the number of runways available at the airport. Figure 1 shows the airport diagram for JFK [2].The Port Authority owns and manages the area airports, and receives fees for usage [3]. Operating at a lower efficiency than necessary negatively impacts NY taxpayers, airline operators, and customers. However, requests to the Federal Aviation Administration (FAA) to increase the caps must be coupled with objective analysis to provide sufficient confidence that these changes will not overload the airports and airspace.

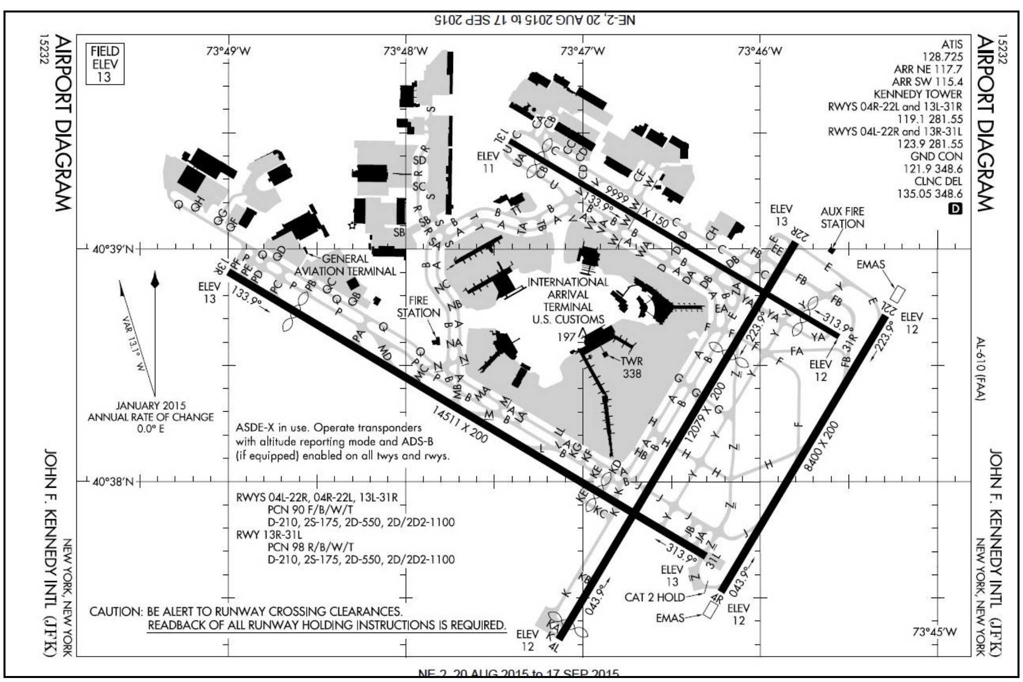

Figure 1: Airport diagram for John F. Kennedy

## JFK Description

New York’s Kennedy Airport is located on Jamaica Bay in Queens, NY, and is operated by PANYNJ. JFK is a large airport which covers nearly 5000 acres. The airport has 4 runways which can each be operated in either direction to accommodate winds, and the runway usage varies to best accommodate arrival and departure volume. Configurations for the airport are published by the FAA and listed on the Operational Information System (OIS) web page [4]. More information about most of the configurations, including values for the Aircraft Arrival Rates (AAR) and Aircraft Departure Rates (ADR) and whether the configurations are typically used to favor arrivals (“arrival priority”) or to favor departures (“departure priority”), are provided by the FAA’s webpage “JFK Tips” [5]. Table 1 presents information from both sources, with the AAR and ADR noted for each of the configurations listed.

| | Arrival | Departure | AAR | ADR |
|---|---|---|---|---|
| 1 | VOR 13L/22L | 13R | 54 -60 | 30 - 32 |
| 2 | ILS 13L | 13R | 36 - 38 | 30 - 32 |
| 3 | ILS 22L | 22R | Not Listed | Not Listed |
| 4 | VOR 22L | 22R/31L | 34 - 38 | 54 - 60 |
| 5 | ILS 22L/22R | 22R/31L | 42 - 44 | 44 - 50 |
| 6 | ILS 04R/04L | 04L/31L | Not Listed | Not Listed |
| 7 | ILS 04R | O4L | 34 - 36 | 36 - 38 |
| 8 | ILS 31R VAP 31L | 31L | 56 - 60 | 22 - 24 |
| 9 | STAGGERED 31R/31L | 31L | 44 - 52 | 20 - 22 |
| 10 | SIMOS 31R/31L | 31L | 56 - 60 | 20 - 22 |
| 11 | ILS 31R | 31L | 33 - 35 | 38 - 42 |

Table 1: Current day configurations for Kennedy Airport

Though the airport has four runways, no current day configuration uses all runways at the same time. Several configurations use a shared runway for departures and arrivals. When sharing, the volume of arrival traffic directed to the shared runway is moderated by the controllers to provide more departure opportunities when necessary, though typical usage for these configurations traditionally favors either departure or arrival priority.

## Unrealized Existing Capacity versus Capacity Limitations

One of the objectives of this analysis was to identify areas in current day airspace structure and operations with unrealized capacity, as well as areas that are truly achieving nearly their maximum capacity. In the case of unrealized capacity that already exists, operational changes may be sufficient to achieve higher efficiency for the airport. In cases where the runways and routes are already capacity-limited, new technologies could potentially improve throughput. Here, unrealized capacity means that the existing system could accommodate more traffic, but is being underutilized, either intentionally or unintentionally. For example, arrival controllers might spread aircraft homogeneously as they descend to their final approach without need or incentive to target minimum spacing requirements. This makes sense to reduce the workload to manage the flights, but could appear to an observer to be a real capacity limit situation, which it is not. For airports with caps (or any other volume management technique), real capacity operation usually is only revealed for very brief periods when recovering from a disruption and so cannot be derived comprehensively from historic data. However, true capacity can be computed by considering all the mathematical contributors and accommodating uncertainties (wind, pilot compliance timing, etc.) through additional added spacing (referred to in this text as “safety buffers”). In practice, this computed maximum capacity can be difficult to achieve. Yet understanding the potential is critical to objective measurement of how the system is performing.

Baselining current systems against this theoretical capacity is also critical in the decision-making process for application of new technologies. When new NASA technologies are applied to problems that seem to have real limits but are actually areas of unrealized capacity, little benefit often results. This can undermine confidence in technologies that have real promise.

## Tools and Methods

### A. The Arrival Capacity Calculator (ACC)

The ACC analysis tool was used extensively in this work. This tool was created by NASA Langley Research Center (LaRC) in 2010 to objectively compute the capacity of arrival routes and runway configurations that were developed for systems-level NAS-wide simulations to support arrival capacity studies [6]. NAS-wide simulations allow recorded traffic patterns to be used in a time-based scenario to evaluate the impact of configuration changes or new technologies on the overall flow. Depending on the complexity of the scenarios being evaluated, a single time-based simulation run can take many hours to complete. Errors made in configuring the routes or runways are not obvious during setup, and considerable time can be wasted on unintended configurations. Additionally, real flow issues with routes (for example, overcapacity at a shared fix) can be difficult to distinguish from route configuration errors with valuable research insight at stake. The ACC tool was designed to output an image of the routes configured in a format that can be loaded into Google Earth for visual inspection. It also outputs text-based tables of computed characteristics for each fix along the route, including the maximum throughput. This throughput is the maximum possible (the capacity) for that specific set of conditions for steady state flow under sufficient supply volume.

Capacity is not a single, static value for a real world airspace. While the fix locations do not move, the crossing speeds at those fixes can vary as aircraft encounter wind while holding airspeed. Opportunistic groupings of aircraft of like-type allow more fix crossings for the same groundspeed than heavier aircraft that must have additional wake spacing applied. Historic values of arrivals and departures are used to inform the Air Traffic Control System Command Center (ATCSCC) for how much throughput to generally expect under different configurations [5]. However, these historic throughput values are also influenced by the slot caps in place when the data was gathered. The airport might have accommodated more traffic, but the caps limited the volume of traffic.

Any single condition can be used by the ACC tool to determine the steady state capacity for that specific point. However, the tool is most useful when ranges of values are specified to generate a set of reference data to identify the capacity landscape. This provides a baseline against which time-based simulation runs can then be compared. It also serves as verification for those runs. A simulation result that returns a higher throughput than the computed envelope by ACC would indicate that the tested configuration had more optimal conditions than were configured for the tool. For example, the traffic mix or speed profile may have been more favorable than expected. Lower than predicted maximum throughput is typical for both real-world and simulated operations because full efficiency is seldom possible (except for brief periods) due to insufficient sustained volume and inefficiencies in arrangement of traffic. Application of capacity-improvement technologies can then be added to the simulations to try to regain some of the efficiency losses.

For the ACC runs, an additional spacing buffer of 5% was applied beyond the minimum required spacing to match observations of real NY airports during high efficiency. These high efficiency levels typically occurred during the highest volume conditions and presumably at the cost of high controller workload. The tool was used to compute several sets of capacity envelopes with combinations of pre-RECAT and post-RECAT wake spacing, fast and slow generalized speed profiles, and for current day and novel airport configurations.

### B. Aerobahn Video Data

Video captures of real traffic under different airport configurations proved invaluable for understanding the operations to configure the runs. These videos were captured by the Port Authority using a monitoring program called "Aerobahn". The Aerobahn tool [7] provides a visual monitor of traffic on the airport surface and within a few miles on arrival or departure and is used by ground movement controllers who issue instructions to arriving and departing aircraft to gates, runways, and holding areas during high volume. PANYNJ uses Aerobahn actively to manage ground traffic at JFK and for playback with stored data for continuous quality improvement. Some of these recordings were provided for the analysis with the airport in different runway and weather conditions.

### C. Subject Matter Insight

It is critical to capture the correct assumptions and use cases when configuring the analysis tools. This was one of the key roles of the subject matter expert for the NY airspace – Ralph Tamburro, Program Manager for Delay Reduction for the PANYNJ. Without input from the subject matter expert, nuances in operations that represent real-world constraints might be mistaken for simple inefficiencies.

## Capacity Effectors

Many aspects of the airspace system can impact the overall throughput. The available departure and arrival slots at the runway are a limiting factor, but situations along the routes or in the way traffic is managed can cause greater restrictions than just those seen at the runway. The values computed for the various configurations by the ACC represent the best values possible for those conditions, with a standard safety buffer of 5% included for these analyses. Real world operations can achieve close to these maximum values with high controller skill or with the help of technology tools, though sometimes at the cost of high workload. For higher capacity configurations, the slot caps for JFK do not allow the volume of traffic necessary to achieve the maximum values computed and so these caps can also limit the throughput of the airport.

### D. Runways and Runway Configurations

The maximum throughput at thresholds of runways that are unshared (used only for departure or only for arrival) and that operate independently is relatively easy to compute. Mathematically, these values are limited by required spacing between aircraft immediately before touchdown or after takeoff, by runway occupancy rules, and by groundspeed. In practice, these maximums can be difficult to achieve (even with the applied 5% additional spacing buffer set for the runs) because real-world behavior is not optimal. For example, the controller may release an aircraft for departure as soon as FAA rules allow, but the departing pilot may take his time to begin his takeoff roll.

Computing maximum throughput for shared runways (used for interleaved departures and arrivals) is more complicated. Kennedy uses many configurations with a shared arrival/departure runway, and during the course of the day adjusts the usage of the shared runway to favor departures or arrivals as traffic flow dictates. The runway time required for arrivals versus departures is generally not one-to-one, so the true shared runway capacity value differs depending on the usage. This makes derivation of the capacity for the shared runway very difficult based only on historical data values. For example, historic total operations data might show different values for the shared runway during two time intervals with both at capacity since one represented arrival-priority operations and one was departure-priority. Understanding the true capacity is clearer using a measurement tool, as was used in these analyses, because the exact sharing usage is set by the user. For the cases analyzed for this study, arrival priority was used to first fit as many arrivals to shared runways as feasible, with departures staged between arrivals when possible. This allowed a consistent reference frame for comparing different configurations. It also represents a more conservative estimate of the capacity for most conditions.

Other nuances of shared runway usage during two-runway operations are important, so worth noting. For the arrival-priority scenarios used for this analysis, the maximum throughput for a shared runway can be higher than what would be possible if that runway were used exclusively for arrivals. This is because departures can usually be accommodated between *some* arrivals without impacting the arrival timings. Therefore, the total number of operations (arrivals plus departures) will be higher than if no departures were used (for arrival priority situations, the way Kennedy stages two-runway configurations). However, more departures are usually possible within an uninterrupted time span than arrivals. Therefore, if arrivals were restricted to a single runway, more total traffic could usually be handled in the same time span because the number of departures for a dedicated departures-only runway often exceeds the number of combined departures and arrivals possible for that same runway if it were operated shared. In the first case with two runways using one shared runway and one dedicated arrival runway, the computed value for operations per hour per runway (ops/hr/rwy) would be higher for an arrival priority scenario. In the second case using two runways with each dedicated to either departure or arrival traffic, the operations per hour (ops/hr) would probably be higher. This would be true regardless of what priority was being used. However, during periods of high arrival volume, a single arrival runway may not accommodate all of the arrival volume so may not be possible.

Real-world facilities also make tradeoffs to balance efficiency and staffing. More efficient operations usually cause higher controller workload, so efficiency may be relaxed when not considered necessary, as with low volume times of the day. On visual inspection, however, it can difficult to determine if the lower volume operations are a result of choice or of efficiency loss since both present themselves similarly – aircraft are spaced with slightly more distance than what is required by FAA minimum required separation (MRS). This is another case where historic data is a poor analysis method for determining capacity since low volume traffic separated to reduce controller workload look similar to high volume traffic with unintended inefficiencies in spacing. Use of an analysis tool like the ACC can be very valuable to inform the potential capacity of the airspace, regardless of which was the case.

When using a runway for shared arrivals and departures, staging departures opportunistically between arrivals is easiest for arrival streams with larger gaps for wake spacing. As the gaps between arrivals shrink (as with new RECAT spacing), “fitting” departures is harder or sometimes not possible at all for the mathematical case. For the

real-world case it can be worse because departure controllers have to deal with uncertainty in the time it will take a pilot to respond to instructions. If the departure queue for the shared runway grows too long, controllers may switch to departure priority by extending spacing between arrivals (beyond the required minimum) to get the departures out. Departure throughput is increased at the expense of arrival throughput. Real-world uncertainties make it difficult for shared runway operations to realize true capacity levels. Knowing the theoretical capacity, however, is critical to understanding where unrealized capacity already exists versus areas where technology tools are required to achieve higher throughput.

*1. Independent Parallel Runways*

In order to run arrivals to parallel runway independently, FAA rules require a 4300-foot offset between centerlines and also the use of a monitor controller for each runway operating as independent. Runways 31L and 31R meet the geometry criteria, but staffing considerations do not always allow for the monitors, and so these runways sometimes run using a 2-mile stagger. Note that runways 13L and 13R (the opposite flow for 31L and 31R) are not currently used simultaneously for arrivals because of airspace limitations leading to final approach.

In some cases, the FAA now also allows Simultaneous Offset Instrument Approaches (SOIA) for runways with centerlines separated by less than 3000 feet with one final approach localizer course offset by 2.5 to 3.0 degrees [8], also with the use of a monitor controller for each runway operating as independent. This geometry condition is met at JFK for parallel runways 22L and 22R, though no current day configurations take advantage of this allowance yet. Runways 22L and 22R (or 4L and 4R for the opposite flow) often run using a 1.5 mile stagger which is not as efficient but does not require the monitor controller. (Note that 4L and 4R would not qualify here because the localizer does not have the mandatory localizer offset.)

*2. Staggered Parallel Runways*

Stagger operations can have a significant impact on throughput, depending on the type of traffic being handled and on the stagger distance that must be used. The FAA requires 1.5 NMi spacing to an *adjacent* runway leader for arrivals to runways that are separated by 2500 to 4300 feet. For runways spaced between 4300 and 9000 feet apart, the FAA requires 2 NMi spacing to the adjacent runway leader (Figure 2). For Kennedy Airport, runways 22L and 22R (4L and 4R) are 3000 feet apart and can use the 1.5 NMi stagger. Runways 31L and 31R (13R and 13L) are 6700 feet apart and must be staggered (when operated in stagger) at 2 NMi.

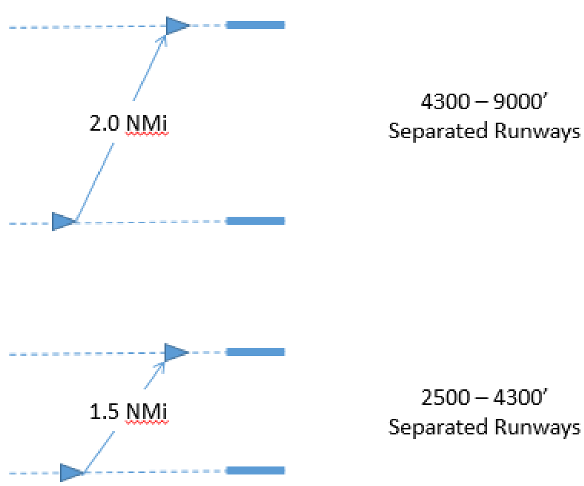


Figure 2: FAA stagger separation requirements for different runway separations

The stagger operations can impact the capacity in two ways. First, in situations of steady traffic to both runways, the geometry of the stagger can force same-runway aircraft pairs to have larger minimum required spacing than what would be required by standard wake spacing. This is true for runways 31L and 31R at Kennedy Airport. In this case, using the geometry of the 2 mile stagger required for the existing runway separation, the spacing behind an adjacent-runway follower (in the path of the approach) is approximately 1.67 NMi. For interleaved arrivals to both runways, this 1.67 NMi is imposed back to the adjacent runway, and cumulatively this forces the same runway traffic into a minimum 3.34 NMi following distance (Figure 3). For many aircraft types, these leader/follower pairs might

otherwise have used 3 NMi separation, or in some cases 2.5 NMi. So stagger operations to Kennedy 31L and 31R prevents these runways from achieving independent runway capacity.

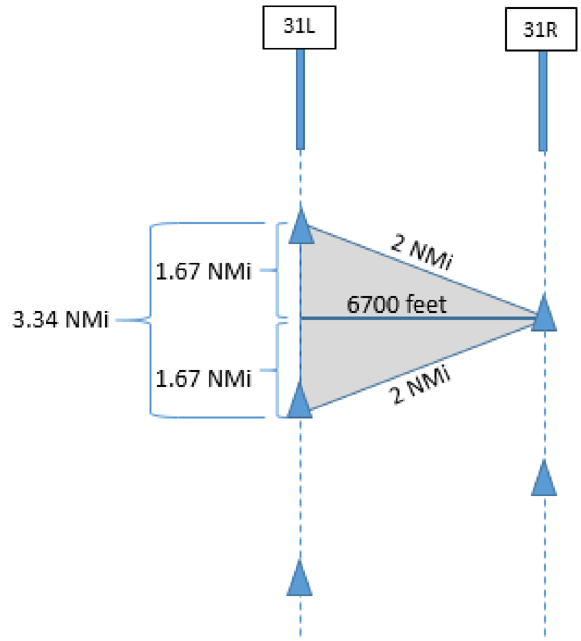


Figure 3: Stagger spacing forcing increase in the minimum spacing to same-runway arrivals

The second impact is in the unnecessary propagation of wake spacing minimums from one runway to the adjacent-runway traffic. This situation is illustrated in Figure 4, and applies to either stagger condition (1.5 or 2.0 NMI). In this case, aircraft spaced for wake restrictions to one runway impact the adjacent runway traffic through the stagger criteria, and effectively propagate wake spacing to leader/follower pairs that do not otherwise require it.

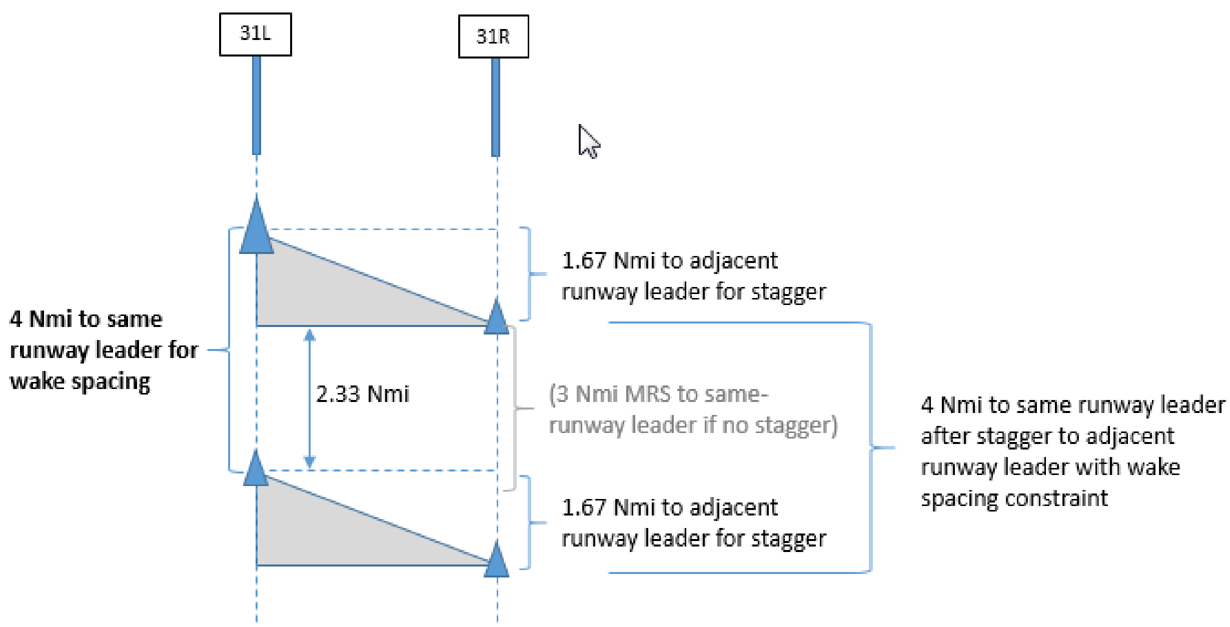


Figure 4: Wake spacing minimums forcing additional spacing to adjacent-runway traffic

Less impact of stagger occurs with runways 22L and 22R because these runways can operate with a 1.5 NMi stagger. The geometry of the stagger computes to a 2.84 minimum separation which is greater than the standard 3 NMi separation for the TRACON (Figure 5). However, stagger operations here do prevent use of the 2.5 NMi reduced separation and also still impose wake spacing constraints from one runway to the adjacent-runway traffic.

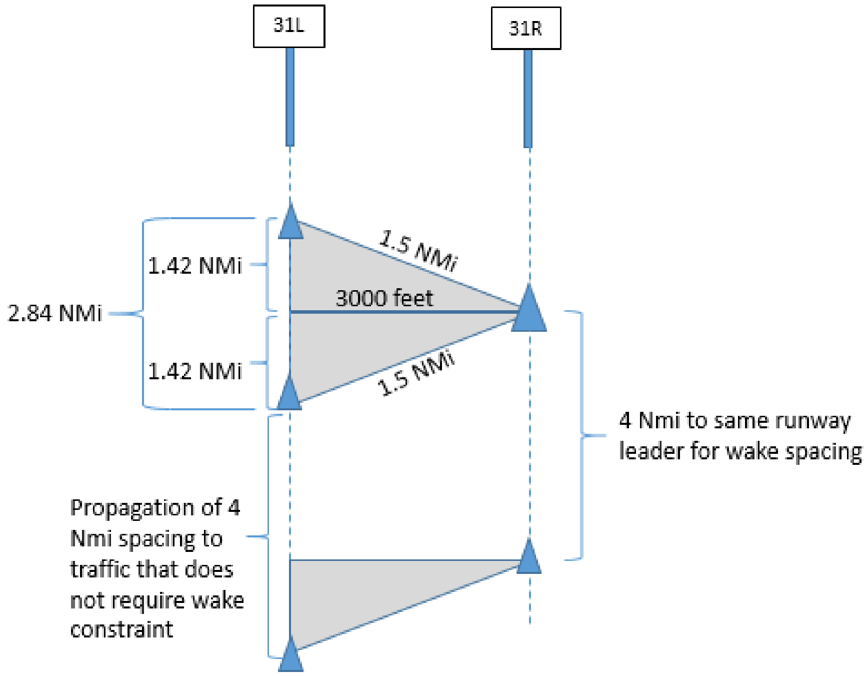


Figure 5: 1.5 mile stagger impact

It is possible to envision a 1.5 mile stagger operation that would mathematically achieve nearly the same efficiency as independent runway operations in highly controlled situations. However, this would be difficult to achieve in real-world use because it would require perfect synergy in type-pairing between the two arrival streams with simultaneous precise adherence to minimum following distance by each aircraft to their respective leaders. Pairs of aircraft would approach the runways with the coordination of fighter jets flying in formation. In practice, this is not the case. For the analysis cases run for this study, a standard efficiency factor of 70% (0.7) was referenced for the stagger cases which was computed using observed spacing values for stagger and non-stagger operations for individual runways. This value was assumed to represent the cumulative impact of the various sources of uncertainty in the system and the controllers' practices for managing those uncertainties.

### 3. *Converging and Crossing Runways*

Converging and crossing runways have an efficiency impact with the severity depending on the geometry of the runways and how they cross. The airport layout for JFK Airport has areas where the extended runways cross. However, sometimes the operation areas are staged to decouple them. For example, when runway 31L is used for departures, most departure rolls are initiated from a point west of the intersection of 31L with 22R (Figure 6) which allows departures to be released independent of arrivals to 22R.

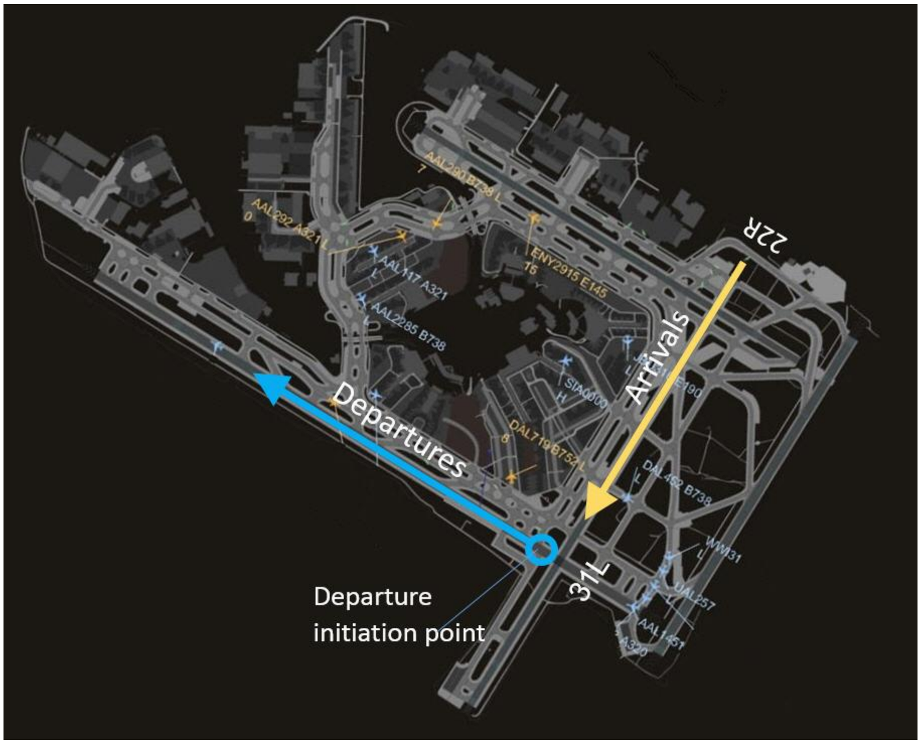


Figure 6: JFK departures from 31L initiated after the crossing point with arrival runway 22R

If active runway crossing points cannot be circumvented in this way, traffic must be managed to prevent the possibility of two flights simultaneously occupying runway or air space. Departures that cross an active arrival runway are not released until the intersection is clear of traffic and departures must be past the crossing point before the next arrival touches down. For JFK, some departures must cross airspace identified for missed approaches, which potentially impacts departure throughput because of Converging Runway Operation (CRO) requirements. Spacing rules are also imposed on flights that will cross the wake of an aircraft in a heavier weight class while still airborne, whether departing or arriving. This acts as an additional constraint to the operations and can result in significant reduction in throughput compared from what would be possible for the same runways decoupled. For JFK, this had to be considered for one of the novel runway configurations discussed later in this paper which proposes arrivals to both 31R and 22R.

## Analysis Description

### E. Route Configurations

*4. Shared Departure Fixes*

Some configurations for the NY airspace require two airports to share a common departure fix. Kennedy Airport shares no departure fixes with other airports and so this effect was not included as an impact to departure capacity for the analysis performed. However, in some cases, departures from JFK must cross a single fix which can limit the departure capacity (especially when a slower aircraft is leading). Airspace usage constraints for individual airports in NY's N90 Center also can force departures into a single stream for longer periods of time, potentially limiting the flow. These departure constraints were considered minimal for the configurations analyzed, particularly because the configurations used arrival priority.

*5. Shared Arrival Fixes*

Shared fixes in arrival routes are considered by the ACC analysis tool for both merges and splits. A merge is when two streams blend to become one. A split occurs when a single stream is divided into two streams, as when arrival traffic from a single region is split to different parallel runways. Almost all arrival routes have merge points since flow from all directions is being funneled to a few runways. It is also not uncommon for traffic to merge in the outer portion of the arrival routes, and then later split to balance runways.

Merge points do not necessarily cause bottlenecks, especially those that are still far from the runway threshold where aircraft are moving at faster speeds. However, there are several ways that efficiency loss can occur. Efficiency can potentially be lost when two streams approach the fix from different wind directions. In the worst case scenario, one aircraft faces a pure headwind and the other a pure tailwind. If the two aircraft are flying a similar airspeed, their groundspeed will differ by twice the wind speed. For example, in Figure 7 the two aircraft flying 200 knots airspeed end up at 160 knots and 240 knots groundspeed when facing a 40 knot wind from opposite directions. The differences in groundspeed between the two aircraft and the change in groundspeed as each completes the turn adds significant uncertainty to the timing of the merge that must be managed by controllers. Mitigation of this uncertainty is usually handled with additional spacing. This contributes to reduced throughputs observed for some real-world configurations in high wind conditions.

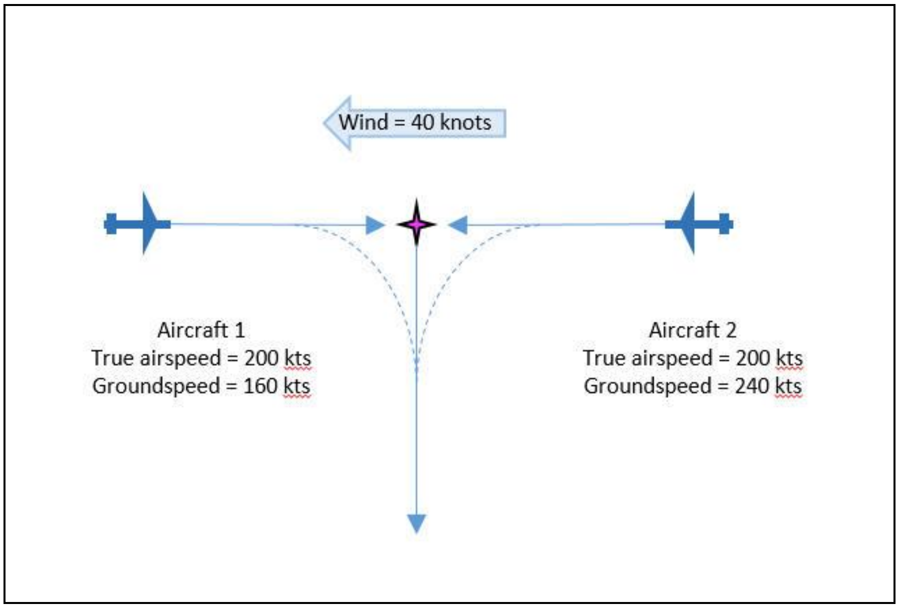


Figure 7: Aircraft at same airspeed with different groundspeeds due to wind

A split point is the opposite of a merge point. This is a fix where traffic splits into two or more streams as it exits the fix location. This commonly happens when heavy traffic from a single route is split to use two or more runways. Traffic that splits at a fix might seem to offer no capacity issue because each stream is less crowded after the split. The impact, however, occurs when the fix at or before the split cannot accommodate enough traffic for both exiting streams to achieve capacity to the targeted runways. The closer the split to the final approach fix, the more likely this problem because aircraft nearer to the airport are slower (resulting in lower total capacity at that crossing fix). This situation is more likely at times of the day when very high volume from one region dominates the arrival flow. At these times, there is less traffic from other compass points merging after the split to fill any gaps that were created.

The ACC tool decomposes the routes configured for a run and computes capacity at each fix in sequence and in consideration of the merges and splits. To model the situation of very high volume from a specific region, the user can vary the volume to the arrival fixes independently. However, for the runs analyzed for JFK for this study, sufficient traffic was assumed to be present from all directions to fully load the arrival streams which could be a source of inflated throughput values when compared to historic arrival rates. With significant constraints to the airspace for NY, further analysis of the impact of unbalanced traffic for the current day routes on capacity might be beneficial, and is discussed briefly in the Summary section.

*6. Wake Spacing Rules*

The FAA began rolling out Recategorization of the Wake Spacing Rules (RECAT) in late 2012 using a gradual approach to transition a few airports at a time. RECAT was implemented for the NY airports in March 2015. The RECAT rules impact both the relative size categories of aircraft and the minimum spacing required between some aircraft categories. Figure 8 summarizes the old and new classifications of aircraft by type under RECAT [9].

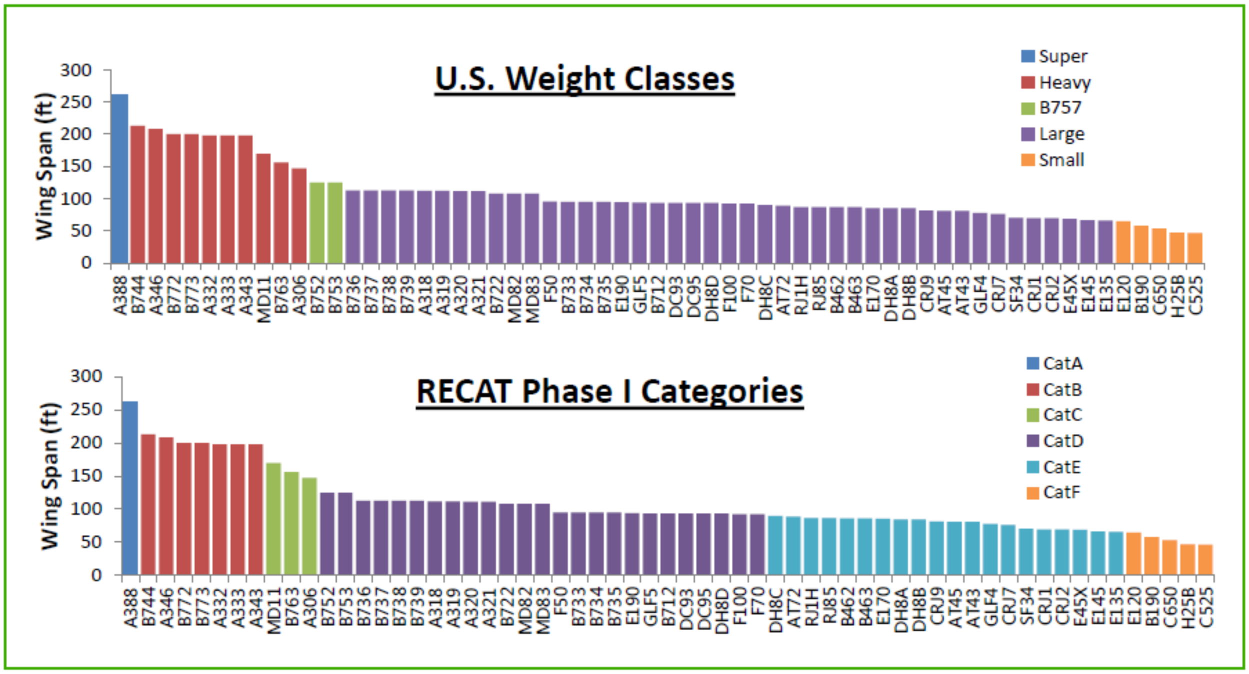


Figure 8: Traditional and RECAT Phase 1 Categories by Aircraft Model

The JFK traffic profile includes a significant number of B757 aircraft, which no longer require special wake rules under RECAT. This change alone is expected to have significant benefit to JFK capacity once the transition to RECAT during arrival and departure operations is complete. The wake spacing requirements for several aircraft pairings were also reduced, which also is expected to provide throughput benefit to JFK (Figure 9) [9]..

| Traditional Weight Classes | Follower | | | | |
|---|---|---|---|---|---|
| | A380 | Heavy | B757 | Large | Small |
| A380 | MRS | 6.0 | 7.0 | 7.0 | 8.0 |
| Heavy | MRS | 4.0 | 5.0 | 5.0 | 6.0 |
| B757 | MRS | 4.0 | 4.0 | 4.0 | 5.0 |
| Large | MRS | MRS | MRS | MRS | 4.0 |
| Small | MRS | MRS | MRS | MRS | MRS |

| Recat Categories | Follower | | | | | |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | F |
| A | MRS | 5.0 | 6.0 | 7.0 | 7.0 | 8.0 |
| B | MRS | 3.0 | 4.0 | 5.0 | 5.0 | 7.0 |
| C | MRS | MRS | MRS | 3.5 | 3.5 | 6.0 |
| D | MRS | MRS | MRS | MRS | MRS | 5.0 |
| E | MRS | MRS | MRS | MRS | MRS | 4.0 |
| F | MRS | MRS | MRS | MRS | MRS | MRS |

FAA Order 7110.659, Table 5-5-2

No Change
Separation Decrease for Entire Category
Separation Decrease for Part of Category
Separation Increase for Entire Category
Separation Increase for Part of Category

*Values in the table represent separation requirements in nautical miles. MRS is Minimum Radar Separations.

Figure 9: Separations for traditional and RECAT aircraft categories

### *7. Airspeed Profile*

The airspeed profile describes the speed used as an aircraft decelerates from the arrival fix at the outer margin of the TRACON to the runway threshold for arrivals, or in the opposite direction from the threshold to the TRACON boundary for departures. Arriving aircraft have to obey a TRACON speed limit, but are allowed to manage their speed within that limit (often using the onboard Flight Management System, or FMS) unless directed differently by ATC. Speed adjustment is the primary method of separation management by TRACON controllers for aircraft on Standard Terminal Arrival Routes (STARs) when the unaltered trajectories that will cause loss of separation. Increased spacing can be provided either by slowing the followers or by keeping the leaders on a faster trajectory than they would have used by default (arriving aircraft are never asked to increase speed).

As the traffic slows, it also compresses as followers naturally catch up to their leaders. The amount of compression is governed by the pace of deceleration. If the deceleration is constant throughout the arrival, the compression will occur gradually across the TRACON. Conversely, a rapid deceleration in either the outer TRACON or near to the runway can concentrate the compression to that location. Forcing the compression to occur shortly after entering the TRACON facilitates maintained separation for the rest of the descent as might be needed for Instrument Metering Conditions (IMC). Forcing the compression to occur late in the arrival and nearer to final can be used to help realize 2.5 mile reduced spacing for Visual Metering Condition (VMC) operations.

Since the speed profiles play a role in the arrival throughput for the airport, two profiles were used for comparison to generate the ACC analysis results and were based on instructions issued by controllers to arriving aircraft during high volume periods. Some controllers managed the volume by slowing the followers and others by holding the leaders at higher speeds. These aural observations were made by listening to voice traffic between controllers and arriving aircraft to Kennedy and Newark Airports [10] for times that corresponded to the video playbacks (from Aerobahn). The "Slow" profile results created with the ACC tool are based on a speed of 160 knots at a distance of 5 miles from the runway threshold. The "Fast" profile results are based on 180 knots at that same distance.

### F. Runway Configuration for the ACC Tool

The following details were used to configure the ACC tool for each of the current day configurations. For each configuration, some discussion is also added to identify where real-world uncertainties or complexities can impact the airport's ability to fully realize the full mathematical capacity:

#### *1. Arrival: VOR 13L/22L, Departure: 13R*

In this case, one departure runway and two arrival runways are in use. Departure runway 13R is not shared, but the flight path does cross 22L (arrival) within a mile of the departure end of 13R which invokes the Converging Runway Operations (CRO). An Arrival Departure Window (ADW) is in use for this configuration which limits departures when an arrival is within the identified window. So the runways are technically dependent. Runways 22L (arrival) and 13L (arrival) do not intersect. With the distance between the approach ends being approximately 1.75 miles apart and with aircraft at approach speeds, there is ample time to ensure separation between these aircraft in the event both aircraft were to execute a go-around.

#### *2. Arrival: ILS 13L, Departure: 13R*

Each of these runways was considered to run without dependencies. The ACC tool results are based on maximum efficiency for this case.

#### *3. Arrival: ILS 22L, Departure 22R*

The same assumptions for configuration 2 apply to this configuration. The ACC tool results are based on maximum efficiency for the arrival or departure operations.

#### *4. Arrival: VOR 22L, Departure: 22R/31L*

This configuration uses the same setup as for configuration 3, but with the addition of departure runway 31L. The departures for 31L are typically initiated at taxiway "KE" which is west of the crossing point with runway 22R, so they can be run without dependence on the arrival traffic. In this case, all three runways in use are expected to have full efficiency.

#### *5. Arrive ILS 22L/22R, Depart 22R/31L*

In this configuration, arrivals to 22L and 22R are dependent and had losses applied for stagger efficiency. Additionally, runway 22R is shared for departures and arrivals. The ACC runs are configured to assume arrival priority, so the maximum number of arrivals are first considered for the two dependent arrival runways, and then the departures are estimated to use the available runway time between landings. For real-world operations, the majority of the time that this configuration is used is when departures are heaviest. Therefore, this configuration is more typically used for departure priority with 22R being used as an "overflow" arrival runway when 22L demand exceeds its capacity.

As with configuration 4, departures from 31L are assumed to be initiated from Taxiway "KE" west of the 22R/31L crossing point, so no efficiency loss is applied in computing the departures from 31L.

*6. Arrive ILS 4R/4L, Depart 4L/31L*

The assumptions for this configuration are nearly the same as for configuration 5. In this case, operations are turned around for the arrivals to use the 4L and 4R end of the runway instead of the 22L and 22R side. This again is used primarily when the departure demand is the heaviest and 4L should be viewed as primarily a departure runway with arrivals limited to overflow use only. Departures for 31L are again initiated at Taxiway "KE" west of the runway crossing point with no impact to departure efficiency for this runway. The one exception is that the departures from 4L must be released with consideration of the fact that these aircraft must turn right and cross through the missed approach path to 4R (IFR weather). For real-world traffic, this adds an additional timing constraint on the 4L departures with some departure efficiency loss. One other complicating factor is that the departures for both runways use the same area to taxi to the departure ends of the runway, which adds to the surface complexity.

*7. Arrive ILS 4R, Depart 4L*

This configuration uses nearly the same assumptions as for configuration 3. The additional constraint for real-world operations, however, is that departures from 4L must turn right and cross through the missed approach airspace for 4R (IFR weather). This may cause the ACC results to have slightly better efficiency for this configuration then the real-world counterpart.

*8. Arrive ILS 31R VAP 31L, Depart 31L*

For this configuration, both arrival runways are configured for the ACC tool to operate without dependencies for arrivals. The shared runway, 31L, is configured based on arrival priority with departures released between arrivals.

*9. Arrival: Staggered 31R/31L, Depart: 31L*

Runways 31L and 31R require a 2-mile stagger when using stagger operations because they are separated by approximately 6700 feet. This forces fully interleaved staggered traffic to a minimum spacing of 3.34 NM, rather than the standard 3 NM (or 2.5 for reduced spacing opportunities) which substantially impacts the capacity for high volume (see earlier section for "Staggered Parallel Runways" for description and illustrations). For the ACC analysis, the tool considers the runway spacing and increases the minimum separation values and efficiency to account for this stagger. This is sometimes favored over the Simultaneous (configuration #10) operations because additional controller resources are not required to run staggered approaches. Additionally, AAR numbers are higher for this configuration over the 22's or 4's staggered approaches due to the limitations of the airspace.

*10. Arrive: Simultaneous Independent 31R/31L (SIMOS), Depart: 31L*

This configuration is very similar to that of #8, except that this one is used for IFR/MVFR conditions (as clarified by the previously mentioned "Tips" website). Though controllers respond with more spacing caution in IFR conditions, the main impact for the ACC tool configuration is in the assignment of minimum required spacing (since the 2.5 NM wake spacing reduction requires the Tower controller to be able to see the runway turnoff of arriving flights). This case was configured to assume that the 2.5 NM reduction was not feasible, with the minimum spacing was held at 3 NM. If MVFR conditions allow the controller to see the turnoff, the slightly higher arrival capacity for configuration #8 would apply.

In practice, IFR operations typically have more difficulty achieving full capacity potential for the airport because controllers operate more cautiously and are responsible for separation through touchdown. ILS operations may be good candidates for new technologies that allow realization of more of the capacity that exists in the system mathematically.

*11. Arrive:  ILS 31R, Departures 31L*

The same assumptions for configuration #2 apply to this configuration. The results for these ACC runs were based on the 100% efficiency cases for arrivals and departures. Even though the missed approach path does cross the departure path there is ample time to provide separation between the two aircraft.

### G. Route Configuration for the ACC Tool

The routes to the runways also required configuration. The route configurations are primarily used by the ACC tool to assess bottlenecks upstream of the runway thresholds that can prevent the runways from receiving enough volume to achieve their full capacity. The current day routes were configured using the latest version of the Traffic Management Advisor (TMA) routes for the JFK airspace. TMA is a tool used to predict the arrival times of aircraft to the arrival fix and to the runways, and is available in every Center in the NAS and in some TRACONS and towers

[11]. As previously noted, the actual arrivals to JFK do not connect the final fixes of the STAR routes to the runway approaches. In real operations, this connection is made by controllers who vector the aircraft through those sections of the airspace. However, the TMA routes are designed to extend all the way through the TRACON to the threshold and represent an average path that is the basis for the threshold crossing time estimations. The TMA tool also maintains specific speed profile information by aircraft type. However, for the ACC tool runs, the generalized profile of the tool (which is based on a sampling of historic data for mixed traffic) was used because the type variations were not critical to capacity at fix calculations. Figure 10 shows an example of the TMA routes for JFK with runways 13L and 22L in use for arrivals.


Figure 10: TMA arrival routes for JFK 22L and 13L

### H. Current Day Configuration Results

The results of the analysis runs for these current day configurations are shown in Table 2. These results are presented using both pre-RECAT wake spacing requirements and post-RECAT wake spacing. It should be noted that NY only recently was authorized to use RECAT spacing, and the transition may be easier to make for departures than arrivals. So the full potential of RECAT will likely emerge over time for NY, and actual values for operations (in Figures 11 and 12 of the next section) seem to demonstrate partial transition to date.

| | | | Pre-RECAT | | | | | | Post-RECAT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Slow Profile | | | Fast Profile | | | Fast Profile | | |
| Config | Arrival | Departure | Arrivals | Departures | Total Ops | Arrivals | Departures | Total Ops | Arrivals | Departures | Total Ops |
| 1 | **VOR 13L\|22L** | **13R** | 74 | 32 | 105 | 80 | 40 | 118 | 93 | 45 | 137 |
| 2 | **ILS 13L** | **13R** | 37 | 32 | 67 | 43 | 40 | 82 | 50 | 45 | 94 |
| 3 | **ILS 22L** | **22R** | 37 | 32 | 67 | 43 | 40 | 82 | 50 | 45 | 94 |
| 4 | **VOR 22L** | **22R\|31L** | 37 | 63 | 99 | 43 | 79 | 122 | 50 | 71 | 121 |
| 5 | **ILS 22L\|22R** | **22R\|31L** | 67 | 51 | 117 | 72 | 61 | 132 | 81 | 65 | 146 |
| 6 | **ILS 04R\|04L** | **04L\|31L** | 67 | 51 | 117 | 72 | 61 | 132 | 81 | 65 | 146 |
| 7 | **ILS 04R** | **04L** | 37 | 32 | 67 | 43 | 40 | 82 | 50 | 45 | 94 |
| 8 | **ILS 31R VAP 31L** | **31L** | 80 | 17 | 96 | 87 | 20 | 105 | 100 | 19 | 118 |
| 9 | **STAGGERED 31R\|31L** | **31L** | 65 | 20 | 84 | 70 | 23 | 93 | 79 | 24 | 102 |
| 10 | **SIMOS 31R\|31L** | **31L** | 73 | 18 | 90 | 78 | 22 | 99 | 88 | 22 | 108 |
| 11 | **ILS 31R** | **31L** | 37 | 32 | 67 | 43 | 40 | 82 | 50 | 45 | 94 |

Table 2: Current day JFK configuration analysis results under varied test conditions

For the pre-RECAT results, the values for the "slow" profile and the "fast" profile are also shown separately. For specific descriptions of these fast and slow trajectory profiles and how they impact throughput, see the earlier section "Airspeed Profile". The post-RECAT values show the best case capacity potential, and these cases were run using only the "fast" speed profile to that end.

As previously noted, these results assumed arrival priority and were computed by first calculating the arrivals possible under the given conditions, and then computing departures based on those arrivals. As the arrivals increase for shared runways, the available departure slots goes down. So, for example, configuration #8 has the highest values for arrival operations, but not the highest values for total operations because 31L departures are from a shared runway.

The results of the ACC analysis should be viewed as the potential throughput for the airport as configured for *steady-state high volume* traffic. It is likely that real world values over the span of a full hour in this same configuration will show lower throughput. This is because reaching these maximums requires adequate traffic volume to achieve the operations specified, and in most cases the computed capacity exceeds the current day slot caps (81 for JFK).

Another source of lower-than-capacity throughput can be the variations in approach speeds of individual aircraft through the TRACON because of preference or performance limits. These speed differences create gaps and packs of aircraft as they decelerate to their landing speeds. High volume from a particular region can exacerbate the problem if there is insufficient traffic from other regions to fill gaps that emerge in the flow. These packs of aircraft can appear to be short bursts of high efficiency, but may be preceded or followed by lulls in volume. In some cases, these can be mitigated through controller intervention and speed commands. This may also be an area where new technologies for flow conditioning and ordering could provide benefit.

It is also possible that real-world values could exceed the ACC results for the configured conditions. This should occur infrequently, however, if the ACC runs were configured to truly match the operational scenario. These occasional exceedances would indicate that the real-world operations had a period of controller efficiency or traffic pairings that was better than what was configured for the tool. For example, the tool runs used a 5% spacing buffer, and the controllers may have been able to achieve tighter spacing for the real traffic for some part of the sample period.

### I. Validation of Results

The capacity values computed by the ACC analysis are generally higher than daily throughput seen for real-world operations at Kennedy Airport under these configurations. However, as previously mentioned, the current day traffic volume is limited by slot caps for the airport, and controllers presumably have adjusted operations with those caps in mind. It can be difficult to find real-world periods that provide enough arrival volume to load the system to the degree required to replicate the ACC tool results. However, recent construction at JFK that caused the temporary closure of runway 22R offers data useful for some of the configurations. During the runway closure, PANYNJ received daily reports for throughput, call rates, and runway usage for Kennedy Airport to support Port Authority's monitoring efforts [12]. Figures 11 and 12 are two sample sets of data contained in the reporting. The airport was attempting to maintain standard throughput during the construction period, and some of the configurations offer candidates for nearly fully-loaded operations for comparison against the AAC results. Not all configurations can be replicated. However, validating the subset that is available provides some confidence in the tool results.

For the August 12$^{th}$ data, the airport was using runways 31R and 31L for arrivals and runway 31L for departures for most hours. The two hours showing the greatest number of departures are the 14:00 and 21:00 hours, with 48 and 49 departures respectively. Of the 48 departures in the 14:00 hour, all used 31L. Of the 49 departures in the 21:00 hour, 47 used runway 31L (Figure 12). This suggests that the value of 47-48 departures/hour is the best estimate for the maximum departure rate for runway 31L unshared in the real world operations captured in this data set.

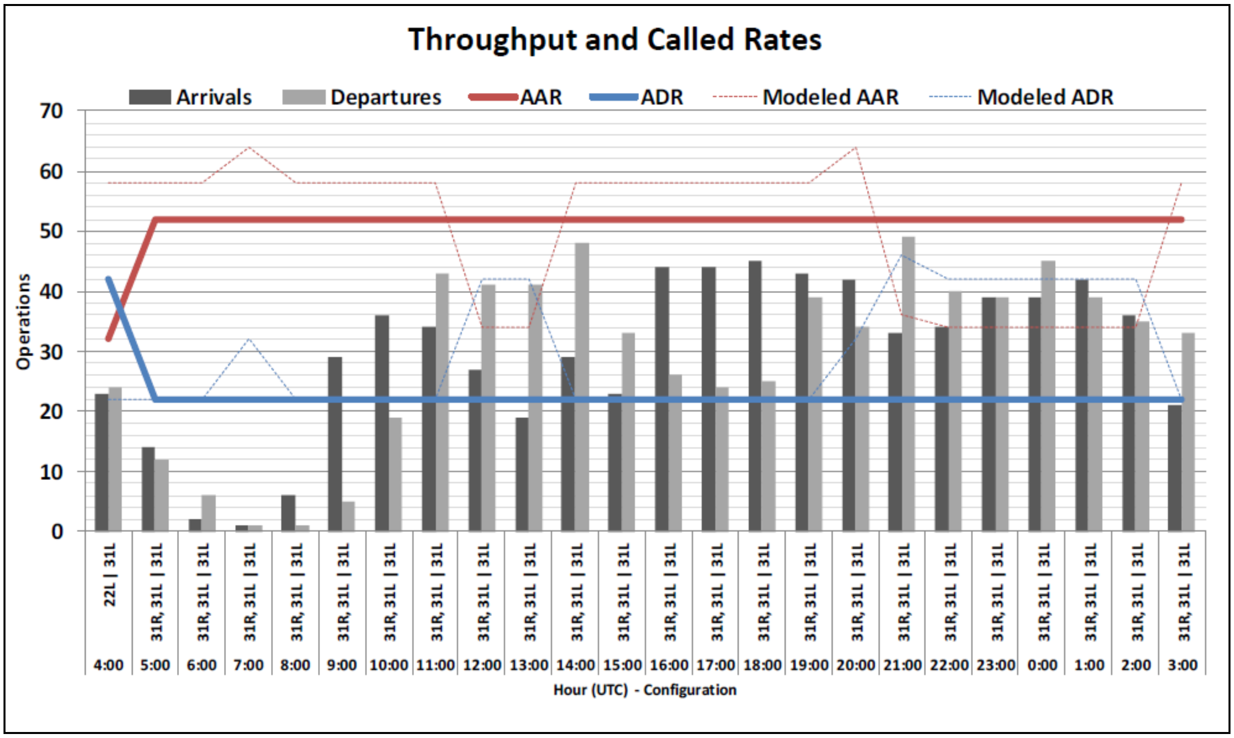

Figure 11: Reported throughput for a traffic day at JFK during closure of runway 22L

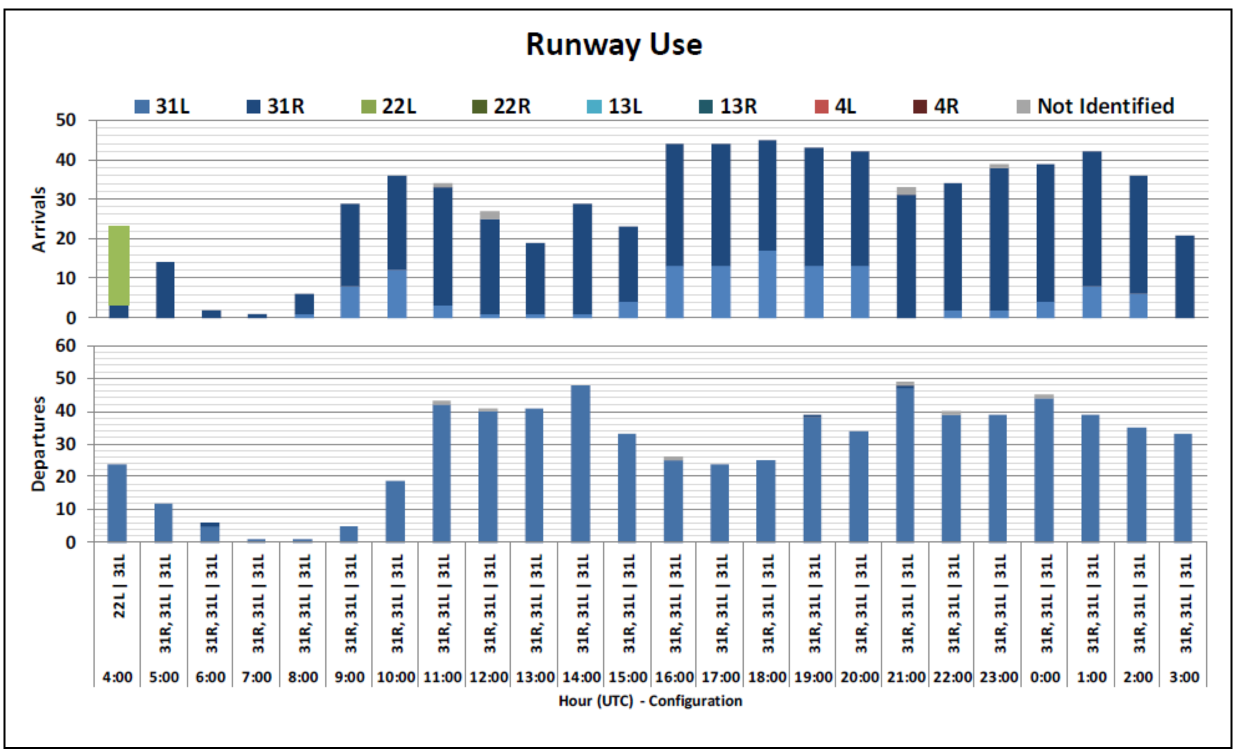

Figure 12: Reported runway usage for traffic day at JFK during closure of runway 22L

For the ACC results, the only configuration specifically using 31L unshared is the last configuration, number 11 of Table 2. However, the departure configuration for the tool for this case was the similar to that of cases 1, 2, 3, and case 7 (single departure runway, unshared). For this set of results, the departure rates were predicted by the ACC tool to be 32 aircraft/hour for the pre-RECAT Slow profile, 40 aircraft/hour for the pre-RECAT Fast profile, and 45

aircraft/hour for the post-RECAT case. The departure controllers have mostly transitioned to RECAT spacing, so the post-RECAT ACC results should be referenced here. This real-world case shows that the controllers actually slightly exceeded the predicted rate of 45 departures/hour for these periods. This means that either the aircraft types that were departed during those time periods were very efficiently arranged, or more likely that the controllers were controlling with higher than predicted efficiency. In either case, the real world results match the predicted results with only about 6% error, and since the ACC results were the lower of the two values it at least shows that the tool did not over-predict capacity for this case.

Using this real-world data for validation of the arrival values has to be done carefully. At first glance, it is tempting to use the highest arrival rates during the day and compare those to the values computed by the ACC tool. However, the airport is under slot caps of 81 operations per hour. During the 16:00 – 18:00 hours (which have the highest recorded arrival rates), the combined departures and arrivals totaled only 68 – 70 operations, so the arrival stream and departure streams were probably not seeing maximum volume. In this case, the arrivals could be using some of 31L simply to balance the stream and reduce controller workload rather than using it because 31R was at capacity. For the 19:00 hour, the total operations were 82 (1 over cap), however the departures were significantly higher than would be the case if arrivals were maxed-out in arrival priority (as with the ACC runs). So this data also is probably not representative of true maximum volume *arrival* conditions.

The data for the 23:00, 0:00, and 1:00 hours do offer a single arrival runway validation opportunity. For these hours, the departure rates were high (39 – 45 departures per hour), and simultaneously the arrival rates were high enough to cause a few of the arrivals to spill over to 31L. So the portions of arrivals to 31R for these hours are useful to validate the single arrival runway condition for 31R, which corresponds directly to ACC configuration number 11 in Table 2, but is also applicable to cases 2, 3, and 7. Figure 12 shows that in these hours, between 34 and 37 arrivals/hour occurred on runway 31R. The ACC tool predicted 37 arrivals for the pre-RECAT Slow profile, 43 arrivals for the pre-RECAT Fast profile, and 50 arrivals for the post-RECAT profile. The subject matter expert indicates that the arrivals controllers have not yet transitioned to the RECAT wake spacing, so the pre-RECAT values should be referenced here. So this real-world data indicates that JFK achieved very nearly the arrival throughput values predicted for the slow profile trajectories. If the traffic was actually managed using the fast profile, the ACC results would indicate that the arrivals were operating at 14 – 21% less efficiency than the maximum possible. (See the sub-section "Airspeed Profile" for the description of "slow" and "fast" airspeed profiles.)

Unfortunately, this data set cannot offer insight for the volume of traffic that would be required to validate the multiple arrival runway cases at true maximum volume. Figure 11 actually shows that the Aircraft Arrival Rate (AAR), or the arrival "call rate", was never above 52. The Aircraft Departure Rate (ADR) is also shown. These call rates are the maximum number of aircraft that the TRACON plans to accept from and deliver to the Center. In this case, the AAR and ADR combined only total 74, which is less than normal due to the runway construction. So this data does not provide a validation opportunity for the multiple-runway AAC configurations.

Another basis for comparison is available through the FAA's "JFK Traffic Management Tips" web page (http://www.fly.faa.gov/Information/east/zny/jfk/jfk_tm.htm). (This page is replicated in Appendix A for reference.) This site lists AAR and ADR call rates for most runway configurations under various conditions, and these values are not reduced by runway construction. In general, call rates may not directly represent capacity because there are many decisions that contribute to how the airport decides to best stage the arrivals and departures to meet their demand. However, they are useful here for comparison without another source data.

Some of the configurations are not easy to match to those listed in the "Tips" site. Some configurations are missing and others are used with departure priority (rather than arrival priority, as with the ACC analysis) which weights the usage very differently. Table 3 lists the configurations that are available and staged similarly to those of the analyzed cases, and compares the AAR and ADR call rates from the web page with the computed maximum throughput values for the same conditions by the ACC tool. Since these AAR and ADR rates were last updated on this site in 2013, the pre-RECAT values were selected for the ACC tool results. The lower value in the range specified represents the "slow" profile data and the higher value represents the "fast" profile data.

The multiple arrival runway configuration case A uses a lower AAR and ADR than the predicted maximums possible from the ACC results. This may be due to slot caps, but may also be due to the runway interdependencies in this configuration with 13L arrivals potentially requiring a missed approach across the 22L arrival path and with 13R departures having to consider timing of 22L arrivals. This may be a configuration where automation or technology tools, in combination with increased caps, could have good benefit for improving arrival efficiency.

| | Configuration | | Call Rates from FAA "Tips" Web Page for JFK Airport | | Computed Maximums with ACC Tool Analysis | |
|---|---|---|---|---|---|---|
| | Arrival | Departure | AAR | ADR | Arrival Rate | Departures |
| A | VOR 13L/22L | 13R | 54 – 60 | 30 - 32 | 74 – 80 | 32 - 40 |
| B | ILS 13L | 13R | 36 – 38 | 44 - 48 | 37 - 43 | 32 - 40 |
| C | VOR 22L | 22R/31L | 34 - 38 | 54 - 60 | 37 – 43 | 63 – 79 |
| D | ILS 31R VAP 31L | 31L | 56 - 60 | 22 - 24 | 80 – 87 | 17 – 20 |
| E | STAGGERED 31R/31L | 31L | 44 - 52 | 20 - 22 | 65 – 70 | 20 – 23 |
| F | SIMOS 31R/31L | 31L | 56 - 60 | 20 - 22 | 73 - 78 | 18 - 22 |
| G | ILS 31R | 31L | 33 - 35 | 38 - 42 | 37 – 43 | 32 - 40 |

Table 3: Comparison of FAA call rate schedule values to computed throughput values by ACC tool

Two versions using arrivals to 13L with departures to 13R are listed in the "Tips" table. One version specifies VFR, and is the source of the values for case B in Table 3 because the AAC analysis tool was configured for best case with VFR assumptions. The range for AAR values is similar to those attained in the analysis. The ADR for this case, however, is much higher than the values predicted by the analysis for the "slow" profile case. In fact, this case has the highest ADR for any of the single departure runway cases listed in the "Tips" table, and the reason for this difference is not clear. If this rate is achievable, however, it may indicate that the ACC analysis tool is overly conservative in its estimate for unshared-runway departure rates. A rate of 48 aircraft per hour would imply an average span of 75 seconds between each arrival, which is not unreasonable.

Case C is included even though the notes column on the website states that it favors departures because this is the only multiple departure runway case with an unshared arrival runway. When departing both 22R and 31L, the 31L departures are usually initiated after the 22L intersection, so the geometry should not negatively impact the capacity here. These departure streams do not share a fix, so the throughput could potentially reach a value of twice the single runway departure throughput of case B, which is what the ACC tool results show. However, this may be a case where the operations are impacted by the cap because the ADR for the "Tips" site is significantly lower than the predicted maximum values in the ACC results and only 10 – 12 departures higher than the previous case that used only a single departure runway.

The three configurations listed for D, E, and F use the same runways, but are staged differently. The configurations use VFR with independent, staggered, and IFR with independent approaches, respectively. In each case, the ACC analysis predicts higher throughput for arrivals than the AAR values. The analysis, however, predicts slightly lower throughput for departures than the ADR values. This may be due to the real-world airport trading off some arrival capacity for departure throughput, or may be due to overly conservative prediction of departure throughput for the AAC analysis.

For the final case, G, the ACC analysis predicted the same throughput as for this runway set with the reverse direction (case B). However, the AAR and ADR listed were lower than their corresponding case B values. This may be due to airspace constraints west of the airport, which forces departures and missed approach arrivals to turn left shortly after leaving the airport.

## Novel Configurations

In addition to analysis for current day configurations, several novel configurations for the airport were investigated. These configurations were selected because they may offer significant benefit potential for the near term, without requiring enabling tools or significant changes to the airspace (though technology tools could enable more benefit to be realized).

The following two new configurations were identified to offer potential near-term benefit:

1. OPD route addition for traffic arriving from the northeast to 22L and 22R
2. Four simultaneous active runways with arrivals to 22L and 31R and departures from 22R and 31L

Each of these configurations is detailed individually.

## J. OPD Route for Arrivals from the Northeast

### *1. Use Conditions*

This route would be used when the airport is arriving to 22L and/or 22R, particularly when international arrival traffic peaks.

### *2. Background*

There are no current OPD routes into JFK (or any of the NY airports). The airspace can support OPD routes, but the complexity of the airspace and the volume of traffic discouraged NY from being an early adopter of this style of routing. OPD routes, however, are now used successfully into several large airports, which helps mitigate risks due to inexperience of designers, users, and controllers of these types of routes.

### *3. Analysis*

This new OPD route could be used with any of the runway 22 arrival scenarios. The results listed in Table 4 show the same throughput potential for the configurations with the OPD added as for their non-OPD counterparts since in this case the capacity limits were not due to route constraints. However, as discussed in the next section, the biggest benefits are expected to be in reduced pilot and controller workload, community noise reduction, and fuel usage.

| | | | Pre-RECAT | | | | | | Post-RECAT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Slow Profile | | | Fast Profile | | | Fast Profile | | |
| Config | Arrival | Departure | Arrivals | Departures | Total Ops | Arrivals | Departures | Total Ops | Arrivals | Departures | Total Ops |
| 12 | VOR 13L/22L with OPD | 13R | 74 | 32 | 105 | 80 | 40 | 118 | 93 | 45 | 137 |
| 13 | ILS 22L with OPD | 22R | 37 | 32 | 67 | 43 | 40 | 82 | 50 | 45 | 94 |
| 14 | VOR 22L with OPD | 22R/31L | 37 | 63 | 99 | 43 | 79 | 122 | 50 | 71 | 121 |
| 15 | ILS 22L/22R with OPD | 22R/31L | 67 | 51 | 117 | 72 | 61 | 132 | 81 | 65 | 146 |

Table 4: Novel configurations using OPD route to 22L and/or 22R

### *4. Benefit*

The predominant benefit for OPD routes in other areas of the NAS has been potential fuel savings. The OPD profile is configured to reduce or remove level-offs along the arrival routes to save cost for airline operators. While fuel savings may be the also be a result for an OPD route into JFK, the primary motivator is to provide an arrival route that is significantly less complex and with less noise to the communities than the current arrival routes. When runways 22L and 22R are in use for arrivals, current day traffic approaching JFK from the northeast follows a zigzag path at low altitude to turn southwest, then northwest, then southwest again across Long Island. Figure 13 shows magenta historic tracks of aircraft approaching Kennedy Airport with the airport using 22L and 22R for arrivals. The white arrow is the current day routing, and the green arrow depicts the proposed OPD route.


Figure 13: Current day arrival trajectory (white) from northeast and proposed new OPD route (green)

Two characteristics of the OPD route contribute to the noise reduction benefit. The first is that most of the route is moved over the Long Island Sound, and so does not over-fly as many communities. Additionally, the OPD route would be designed to keep aircraft at higher altitude longer, which also reduces noise for the communities that will be overflown. The OPD route also significantly simplifies the trajectory and allows pilots using the route to stabilize their approach much earlier. At the same time, the workload is reduced for controllers managing these flights.

*5. Drawbacks*

This route would require an airspace modification to implement. The proposed route crosses through a section of LaGuardia airspace, noted by the red circle in Figure 14. While JFK is currently allowed to use this airspace when landing on 22L and 22R, they are only allowed access to altitudes up to 3000 feet. The OPD route design will require use of the airspace to 5000 to 6000 feet, instead. However, since the LaGuardia route that would be impacted is used for propeller aircraft and very few propeller flights currently land to LaGuardia, the impact to LaGuardia operations is expected to be minimal.

Figure 14: Proposed OPD route for arrivals to JFK 22L and 22R with LGA airspace identified (in red)

A second drawback is that OPD routes can impact the controller workload. OPD traffic has to be merged with non-OPD traffic before final. This requires consideration by TRACON and final controllers of the different speed and altitude profiles presented by the merging traffic streams. The OPD routes can also shift the burden of spacing and delay upstream to Center controllers unaccustomed to managing these trajectories. For example, OPD route flights require more miles in trail between aircraft than their standard profile counterparts for the same arrival rates due to the faster arrival profile speeds. These trajectory differences can result in efficiency loss or extra delay if not managed properly in the Center airspace.

*6. Enabler*

Trajectory-based flow management (TBFM) tools could be a key enabler for the merging OPD and non-OPD traffic streams. With an early freeze horizon, TBFM could predict and mitigate potential conflicts at before entering the TRACON to reduce the workload for the Center controllers.

A second enabler is Terminal Scheduling and Spacing (TSS), which increases use of performance-based navigation (PBN) arrival procedures during periods of high traffic demand. TSS naturally allows merging of multiple streams along the arrival routes, which would reduce the uncertainty and workload to the TRACON controllers as they merge traffic near the final approach fix [13].

**K. 4-Runway Configuration**

*1. Background*

This configuration proposes to use runways 22L and 31R for arrivals with 22R and 31L concurrently in use for departures (Figure 15). Though JFK has four runways, there are no current day configurations that use all of them simultaneously. While the proposed configuration was never used, it was considered for use in the 2009 time frame [14]. At that time it was rejected because it was not seen to provide enough capacity benefit to justify its creation. However, that conclusion preceded the adoption of RECAT for JFK, which substantially changes the capacity potential.


Figure 15: Proposed 4-runway configuration for JFK

Current day configurations for handling peak volume for JFK rely heavily on shared arrival and departure runways with departures occupying the runways opportunistically when arrivals are prioritized, and with some delay to arrivals imposed when necessary during departure priority. The opportunistic slotting of departures between arrival gaps works particularly well when arriving aircraft have additional wake spacing requirements. However, RECAT removes the extra wake spacing requirement for the B757, which represents a significant portion of JFK's traffic. Other wake spacing requirements for type pairs are also reduced under RECAT, so shared runway configurations may limit the benefit realizable for JFK through RECAT if controllers have to extend the spacing between arrivals to accommodate heavy departure volume. Since this novel configuration does not rely on shared runways, "fitting" departures between arrivals is not an issue here.

*2. Analysis*

Throughput analysis for the 4-runway configuration is shown in Table 5. These results show significant capacity benefit for arrivals and departures. These results include some technology assumptions. One is that a controller-assistance tool, like the Converging Runway Display Aid (CRDA), would be used to stage the converging 31R and 22L arrival operations (CRDA as an enabler is discussed later in Section 5, "Enablers"). This allows the arrival throughput results to exceed those previously shown for runways 22L and 22R (4R and 4L) when run in stagger.

| | | | Pre-RECAT | | | | | | Post-RECAT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Slow Profile | | | Fast Profile | | | Fast Profile | | |
| Config | **Arrival** | **Departure** | Arrivals | Departures | Total Ops | Arrivals | Departures | Total Ops | Arrivals | Departures | Total Ops |
| 16 | **31R/22L** | **22R/31L** | 74 | 63 | 137 | 80 | 79 | 159 | 93 | 71 | 165 |

Table 5: Novel configuration with 4 active runways

*3. Benefits*

Use of this configuration requires no changes to the airspace in NY since all of these routes are already in use for the airport, just not simultaneously. The runway usage also provides easy separation of arrival and departure ground

traffic. The biggest benefit, however, is the increase in capacity offered by the configuration, though realization of this capacity would require an increase in the current slot caps for JFK. Because no infrastructure changes are needed, this configuration could be adopted for use in the near term with capacity benefit to the airport. Continued improvement in benefit is possible for the mid-term, also, with the addition of new NASA technologies to pre-condition the flow.

*4. Drawbacks*

Increased throughput comes at the cost of increased controller workload, particularly for the converging runway landings. While the touchdown points of runways 22L and 31R do not overlap, the runway layout causes flights to 22L to cross the wake of an arriving flight to 31R and forces wake spacing compliance, which must be managed by controllers. In addition to workload considerations, this can also have a significant impact on throughput if management tools are not used to help time the arrivals.

*5. Enablers*

A significant enabler for this configuration is the recent adoption of RECAT spacing for NY airports in March of 2015. JFK has many aircraft that were previously spaced as "heavies", which are now Class C or D with reduced spacing requirements. With fewer aircraft requiring additional wake spacing, the management of the converging traffic is simplified and the capacity potential increases significantly from pre-RECAT levels.

Automation and visualization tools also facilitate full realization of the capacity potential for this configuration and help mitigate the workload for controllers. The Converging Runway Display Aid (CRDA) is a tool that was first deployed in the NAS in 1991 and is now available at all terminal automation sites [15]. CRDA provides a visualization to help controllers efficiently time traffic to converging runways with the "ghost" of arrivals to one runway projected onto the other runways traffic stream to assist in timing and separation of the streams. This tool is currently used in Newark, Philadelphia, and Memphis Airports. CRDA is available but not currently used in JFK, though it was used in the past when construction caused the closure of runway 4L/22R for six months in 2014. In this scenario for this proposed 4-runway configuration, Class A, B, and C aircraft to runway 31R would be staged to follow the smaller aircraft (Class D, E, and F) arriving to runway 22L.

Additional benefit could be provided by preconditioning the arrival flow using near-term NASA technologies. With tools like TSS, larger aircraft could be directed more often to runway 31R with smaller aircraft to 22L to best stage the arrival streams for use with CRDA.

## L. Summary

The work described here was performed from March through July of 2015. This work was initiated to gain understanding of the potential capacity of JFK with respect to the current slot caps placed on the system (81 operations per hour for JFK). With the caps in place, it is very difficult to assess capacity potential using historic throughput data. Caps that are too low to fully load the arrival streams prevent evaluation of performance under those conditions. With lower-than capacity traffic a continuing reality, controllers may adjust operations to level workload for that volume, which homogenizes the flow and has the unintended effect of removing evidence of unrealized capacity. The intention here was not to do a detailed investigation into any one aspect of the system, but rather to determine if there was value in looking deeper. With that in mind, the time was spent doing a broad inspection through system analysis of many options, with spot checks to validate when possible as a "sanity check" of the numbers.

The results generated by the ACC tool analysis for JFK capacity imply that there is unrealized capacity in the current day system, and in some cases this unrealized capacity is substantial. These initial results suggest that more study is warranted to test these static results under more dynamic conditions. The novel route concepts investigated also show promise for benefit for JFK. More configurations were considered than what appear in this paper. The two configurations described were highlighted because they offer benefit that is possible with very little change to the current day system. The benefit increases when new technologies are considered, so these novel configurations offer promise for increasing benefit in an evolving airspace. More analysis and testing for these cases is also planned for work in the next phase of study.

A capacity effector that was not analyzed as part of this study, but which may warrant additional inspection, is the general impact of unbalanced volume from different regions throughout the day. In the analysis performed here, sufficient volume was assumed along all of the configured TMA routes to supply the runways. However, if the concentration of traffic primarily loads one or two routes, this can result in less than capacity volume to the runways. The fast-time simulations should reveal some of these issues if they exist, and these can then be analyzed in more depth through the ACC tool.

## Appendix A: The FAA's Traffic Management Tips Web Page for JFK

### JFK Traffic Management Tips

| Land | Depart | AAR | Notes |
|---|---|---|---|
| VOR 13L & VOR 22L | 13R | VFR 54-60 | • Favors Arrivals<br>• Best Airport Configuration<br>• VFR 2,000ft and 3 miles<br>• ADR 30-32<br>• 13R departure roll prior to 22L arrival -3 mile final<br>• 13R departure roll after 22L arrival -1 mile final |
| VOR 13R & ILS 4R | 13L | VFR 54-60 | • Favors Arrivals<br>• Best Airport Configuration<br>• VFR 2,000ft and 3 miles<br>• ADR 30-32<br>• 13L departure rate dependent on 4R arrivals |
| VOR 13L | 13R | MVFR/VFR 36-38 | • Favors Departures<br>• VFR 2,000ft and 3 miles<br>• ADR 44-48<br>• 13R departure roll prior to 22L arrival -3 mile final<br>• 13R departure roll after 22L arrival -1 mile final |
| ILS 13L | 13R | IFR 28-32 | • Favors Departures<br>• ADR 40-44<br>• 13R departure roll prior to 22L arrival -3 mile final<br>• 13R departure roll after 22L arrival -1 mile final |
| ILS 31R & VA 31L | 31L | VFR 56-60 | • Favors Arrivals<br>• ADR 22-24<br>• 31L departure rate dependent on 31L arrival volume |
| ILS 31R & ILS 31L Simo | 31L | IFR/MVFR 56-60 | • Favors Arrivals<br>• ADR 20-22<br>• 31L departure rate dependent on 31L arrival volume<br>• Simo requires monitors |
| ILS 31R & ILS 31L Staggered | 31L | IFR/MVFR 44-52 | • Favors Arrivals<br>• ADR 20-22<br>• 31L departure rate dependent on 31L arrival volume<br>• 2 mile stagger |
| ILS 31R | 31L | ALL 33-35 | • Favors Departures<br>• All conditions; VFR, MVFR, IFR<br>• ADR 38-42 |
| ILS 22L & ILS 22R | 22R | VFR 42-48 | • Favors Arrivals<br>• 1 ½ mile stagger<br>• ADR 28-32<br>• 22R departure rate dependent on 22R arrival volume<br>• Belmont airspace delegated to JFK ILS restricts LGA ops |
| ILS 22L & ILS 22R | 22R | IFR/MVFR 40-44 | • Favors Arrivals<br>• 1 ½ mile stagger<br>• ADR 28-32<br>• 22R departure rate dependent on 22R arrival volume<br>• Belmont airspace delegated to JFK ILS restricts LGA ops |
| ILS 22L & ILS 22R | 22R & 31L@KK | VFR 42-48 | • Favors Departures<br>• 1 ½ mile stagger<br>• ADR 44-50<br>• 22R departure rate dependent on 22R arrival volume<br>• 31L used for DIXIE/WHITE/RBV departures<br>• Belmont airspace delegated to JFK ILS restricts LGA ops |

| | | | |
|---|---|---|---|
| ILS 22L & ILS 22R | 22R & 31L@KK | IFR/MVFR 40-44 | • Favors Departures<br>• 1 ½ mile stagger<br>• ADR 44-50<br>• 22R departure rate dependent on 22R arrival volume<br>• 31L used for DIXIE/WHITE/RBV departures<br>• Belmont airspace delegated to JFK ILS restricts LGA ops |
| ILS 22L & ILS 22R | 31L@KK | VFR 42-48 | • Favors Departures<br>• 1 ½ mile stagger<br>• ADR 38-42<br>• Belmont airspace delegated to JFK ILS restricts LGA ops |
| ILS 22L & ILS 22R | 31L@KK | IFR/MVFR 40-44 | • Favors Departures<br>• 1 ½ mile stagger<br>• ADR 38-42<br>• Belmont airspace delegated to JFK ILS restricts LGA ops |
| VOR/DME 22L | 22R & 31L@KK | VFR 34-38 | • Favors Departures<br>• Best Departure Configuration<br>• ADR 54-60 |
| VOR/DME 22L | 22R & 31L@KK | IFR/MVFR 32-34 | • Favors Departures<br>• Best Departure Configuration<br>• ADR 54-60 |
| ILS 4R & ILS 4L | 4L | VFR 42-46 | • Favors Arrivals<br>• 1 ½ mile stagger<br>• ADR 24-26<br>• 4L depts and 4R missed approach fly 100 degree heading |
| ILS 4R & ILS 4L | 4L | IFR/MVFR 40-42 | • Favors Arrivals<br>• 1 ½ mile stagger<br>• ADR 24-26<br>• 4L depts and 4R missed approach fly 100 degree heading |
| ILS 4R | 4L & 31L@KK | VFR 34-36 | • Favors Departures<br>• ADR 36-52<br>• 31L used for DIXIE/WHITE/RBV departures<br>• 31L depts not used when LGA 13 depts use Coney climb<br>• 4L depts and 4R missed approach fly 100 degree heading |
| ILS 4R | 4L & 31L@KK | IFR/MVFR 32-34 | • Favors Departures<br>• ADR 32-40<br>• 31L used for DIXIE/WHITE/RBV departures<br>• 31L depts not used when LGA 13 depts use Coney climb<br>• 4L depts and 4R missed approach fly 100 degree heading |
| ILS 4R | 4L | VFR 34-36 | • Favors Departures<br>• ADR 36-38<br>• 4L depts and 4R missed approach fly 100 degree heading |
| ILS 4R | 4L | IFR/MVFR 32-34 | • Favors Departures<br>• ADR 32-34<br>• 4L depts and 4R missed approach fly 100 degree heading |

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## References

[1]Palmer, E., “Airspace Operations Laboratory.” NASA Aeronautics and Space Administration. URL: http://human-factors.arc.nasa.gov/groups/AOL/research/nyops.php [cited 21 September 2015.

[2]Federal Aviation Administration, “Airport Diagram; New York/John F. Kennedy INTL (JFK),” URL: http://www.faa.gov/air_traffic/technology/rwsl/media/JFK%20RWSL%20Layout.pdf [cited 18 September 2015].

[3]“Schedule of Charges for Air Terminals.” Schedule of Charges for Air Terminals. Port Authority of NY & NJ. URL: http://www.panynj.gov/airports/pdf/scheduleofcharges-jfk.pdf [cited 18 September 2015].

[4]Federal Aviation Administration, “JFK AAR.” ATCSCC OIS SYSTEM [Online database], URL: http://www.fly.faa.gov/ois/ [cited 1 October 2015].

[5]Federal Aviation Administration, “JFK Tips,” URL: http://www.fly.faa.gov/Information/east/zny/jfk/jfk_tm.htm [cited 18 September 2015].

[6]Glaab, Patricia. “Improvement to Airport Throughput using Intelligent Arrival Scheduling and an Expanded Planning Horizon,” NASA/TM-2012-217762, NASA Langley Research Center, 2012.

[7]Saab Solutions, “Aerobahn - Airport Performance through Optimal Collaboration," URL: http://saab.com/security/air-traffic-management/air-traffic-management/Aerobahn/ [cited 18 September 2015].

[8]Federal Aviation Administration, “Air Traffic Organizational Policy," Order 7110.65V, URL: https://www.faa.gov/documentLibrary/media/Order/ATC.pdf [cited 18 September 2015].

[9]Federal Aviation Administration, “NextGen: Operational Performance Assessment," URL: http://www.faa.gov/nextgen/media/ngpa_2015.pdf [cited 18 April 2016].

[10]LiveATC.net,”Live Air Traffic – From Their Headsets to You," URL: http://www.liveatc.net/ [cited 18 September 2015].

[11]Federal Aviation Administration, “Traffic Flow Management in the National Airspace System," URL: http://www.faa.gov/nextgen/media/ngpa_2015.pdf [cited 18 September 2015].

[12]Federal Aviation Administration, “JFK Construction,"ATO Office of Performance Analysis, 13 August 2015.

[13]Robinson, J., Thipphavong, J., and Johnson, W., "Enabling Performance-Based Navigation Arrivals: Development and Simulation Testing of the Terminal Sequencing and Spacing System," 10th USA/Europe ATM R&D Seminar (ATM2015), Lisbon, Portugal, 23-26 June 2015.

[14]Mundra, Hilton, Smith, MacWilliams, Mayo, Gaydos, “CRDA Operational Assessment Plan,” MITRE Publication MP090294, The MITRE Corporation, October 2009.

[15]Mundra, Bateman, Smith, Mayo, Hopper, Tamburro, “Converging Runway Display Aid in the NAS: Challenges, Successes and Outlook,” 30th Digital Avionics Systems Conference, October 16-20, 2011, IEEE, 978-1-61284-798-6.